

An Internal Analysis of SGP/CART Radiosonde Performance During the September 1996 Water Vapor Intensive Observation Period

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Introduction

The September 1996 Water Vapor Intensive Observation Period (IOP) provided an excellent opportunity to investigate further the operational performance of the radiosondes used by ARM at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site. Although many instrument inter-comparisons were conducted during the IOP, the lack of an accepted absolute standard makes evaluation of the results difficult. By focusing on information obtained from the radiosondes themselves, with minimal reference to external instruments, we hope to eliminate much of the uncertainty associated with comparing different measurement systems.

Background

Previous work, based on analysis of ground checks and of the ascending and descending phases of individual soundings, provided some quantitative estimates of the uncertainty associated with ARM radiosonde temperature and relative humidity values (Lesht 1995). The ground check analysis, in which radiosonde readings of temperature (T) and relative humidity (RH) made in a small desiccated chamber were compared with reference values of RH and T, showed that the sonde RH values are accurate to within $\pm 1\%$ RH at very low RH values when the sonde is at surface ambient temperature and pressure. We also found that the sonde T values are accurate to within $\pm 0.3^\circ$ C, again at very low RH and at surface ambient pressure.

The ground check analysis provides information about the low-RH performance of the sondes across a fairly limited temperature range (surface ambient). In an attempt to extend the analysis to measurements made aloft, we compared data obtained during ascending and descending phases of the same sounding—assuming that the atmospheric state would not change substantially during the time interval between upward and downward sonde passage. The analysis of these pseudo-replicates (ascending vs. descending) showed that the

precision of the RH measurement (estimated by the average difference) aloft is 3% RH (median correlation coefficient of 0.73), and that the precision of the T measurement aloft is 0.4° C (median correlation coefficient of 0.99).

Finally, although both the ground check and the ascending-descending analysis suggested that the radiosonde measurement precision levels are within the manufacturer's specifications, a separate analysis, comparing precipitable water vapor (PWV) obtained from the CART microwave radiometers (MWR) with that calculated from the radiosondes, showed that the accuracy of the sonde RH could be batch dependent and that a large batch of radiosondes used by ARM was incorrectly calibrated (Lesht and Liljegren 1996). This batch-lot dependence of radiosonde accuracy had not been reported in any previous intercomparison study. The experiments we conducted during the Water Vapor IOP were intended, in part, to further examine the magnitude and significance of this batch-dependent radiosonde calibration.

Experiments Done During the IOP

We conducted several experiments to confirm and extend the previous work. Our primary objective was to improve the characterization of CART radiosonde performance with minimal reference to other sensors. The results shown here are based only on comparisons of sondes with sondes and of sondes with calibrated surface sensors.

We added new operational procedures both to provide data needed for the analysis and to improve the response of the radiosondes during the earliest part of the sounding. Improving the measurement of water vapor in the lowest few hundred meters was a goal of the water vapor IOP. The new procedures included adding a pseudo-ground-check procedure to determine how well the sondes measured temperature and RH at a known point (0% RH, ambient temperature). We term this a "pseudo" check because the operators (rather than the system) had to judge the point at which the sondes reached equilibrium. Thus, some additional uncertainty due to

operator effects is expected relative to the ground check analysis reported by Lesht (1995).

We placed the sondes in an aspirated chamber before launch to minimize the effects of solar heating and to improve the sampling of the near surface air. We also installed calibrated sensors to measure pressure, temperature, and relative humidity independently at the sonde launch point. The temperature and humidity sensors were housed in an aspirated shield located within 2 meters of the sonde launch point. Data from these sensors were recorded by the operators along with the corresponding sonde readings just before launch to provide a second “known” point in RH-temperature space.

Most importantly, half of the soundings done during the IOP were made by flying two radiosondes on a single balloon. Sondes from two different calibration months were used during the IOP. The dual soundings included both sondes from the same batch flown together (to determine within-batch precision) and sondes from different batches flown together (to assess between-batch differences).

Sounding Statistics During the Water Vapor IOP

Sounding operations during the IOP began on September 6, 1996 (23:30), and continued through September 30, 1996 (23:30). During this time we flew 257 Vaisala RS-80H-L radiosondes. Other points of interest include the following:

- The calibrated surface sensors were deployed on September 10, 1996 (20:30).
- The radiosonde aspiration chamber was deployed on September 11, 1996 (20:30).
- We did a total of 172 soundings (8 per day), of which
 - 87 soundings used a single sonde (two ground stations, C1 and S01) and
 - 85 soundings used two sondes (on staggered schedule).
- Of the 85 dual-sonde soundings,
 - 46 were mixed calibration lots,
 - 28 were August calibration lots (serial numbers 63XXXXXXX),
 - 11 were June calibration lots (serial numbers 62XXXXXXX).

Results and Discussion

Comparison of the radiosonde measurements with known reference values provided an estimate of the absolute accuracy of the sensors. Figure 1 shows the results of the pseudo-ground-check analysis in which the sonde values of T and RH were compared with ambient T measured by using a certified mercury thermometer and an assumed 0% RH. The pseudo-ground-check test showed that the RH accuracy of the overall population of sondes used was within specifications ($\pm 2\%$ RH) at very low humidity at surface ambient temperatures. This result agrees with our previous work.

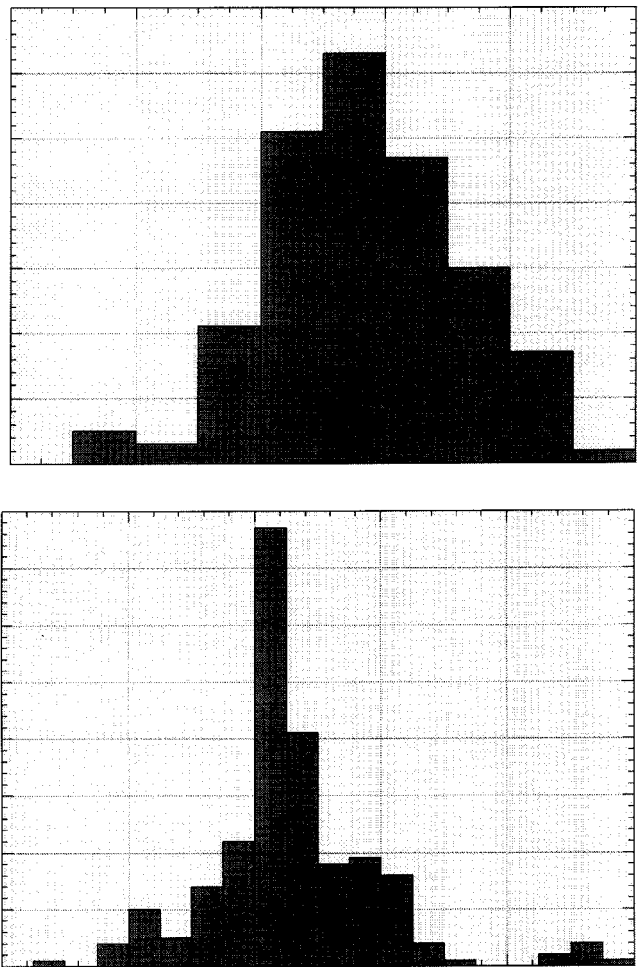


Figure 1. Distributions of the differences between radiosonde and reference RH (top panel) and T (bottom panel) obtained from pseudo-ground-check procedures.

The scatter in the results was somewhat greater, however, than in the formal ground checks performed in 1993-1994. This additional scatter is most likely due to depending on the operators' subjective judgment to determine when the sonde has equilibrated in the ground check chamber.

We also compared the sonde RH and T values just before launch with RH and T values measured by the co-located surface sensors. This comparison was intended to provide a second reference point in T/RH space (ambient conditions) in addition to the point provided by the pseudo-ground-checks. The surface sensor (Vaisala HMP233) had been calibrated recently by the manufacturer and was housed in an aspirated shield located very close to the aspirated chamber in which the radiosonde was placed before launch. The results (Figure 2)

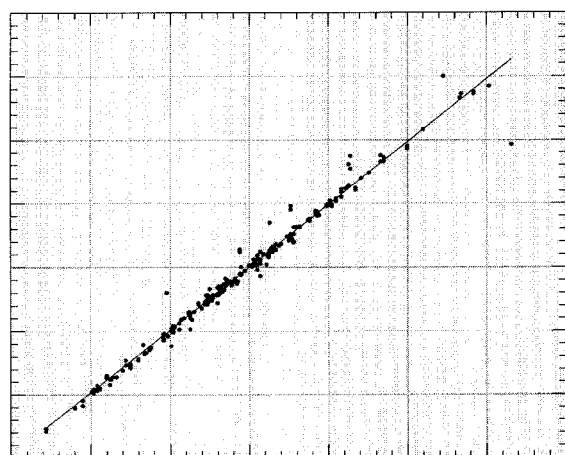
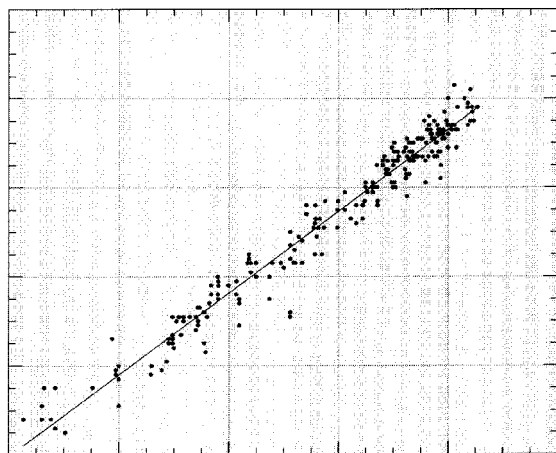


Figure 2. RH (top panel) and T (bottom panel) measured by radiosondes before launch, compared with simultaneous measurements obtained from the HMP233.

show somewhat more scatter in RH than expected and a tendency for the radiosonde RH to be lower than the HMP233 RH at higher RH values.

Some further insight into the uncertainty of the sonde RH and T measurements may be gained by comparing the surface readings obtained from the pairs of sondes used in the dual soundings. Because the sondes are sampling identical air, differences must be related to differences in the calibration of the different sensors. Although these comparisons do not provide information on the absolute accuracy, they do make it possible to quantify the operational precision of the measurements. We found that sondes from the same calibration batch showed no differences in surface RH before launch. Sondes from different calibration batches, however, did show differences, with the June sondes being drier (lower RH) than the August sondes (Figure 3).

The question of how uncertainty in measurement of RH translates into uncertainty in the estimation of the water vapor density profile may be examined by comparing estimates of column-integrated PWV obtained from the sondes used in the dual soundings. These estimates are of particular interest because of the dependence that ARM places on measurements of PWV obtained from MWRs. Figure 4 shows that sondes from the same calibration batch used in dual soundings measure almost identical PWV. On the basis of average observed PWV, mixed-batch flights show June sondes measure approximately 8% less PWV than do August sondes. Note that these results do not speak to the absolute accuracy of the estimates.

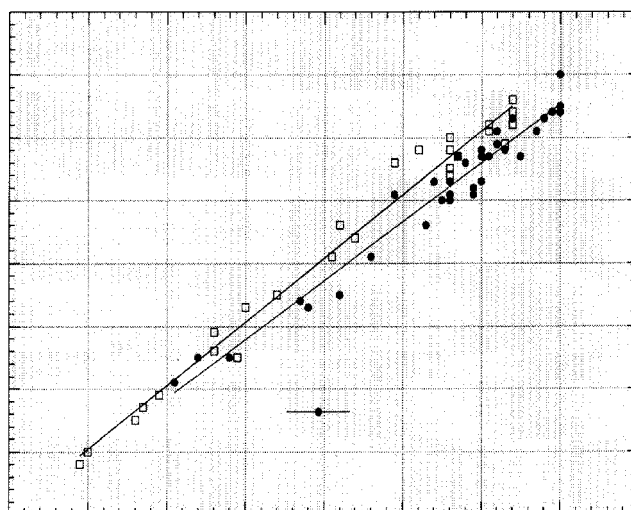


Figure 3. Comparison of RH measured simultaneously by two radiosondes before launch. Results are grouped by calibration batch type (mixed or same).

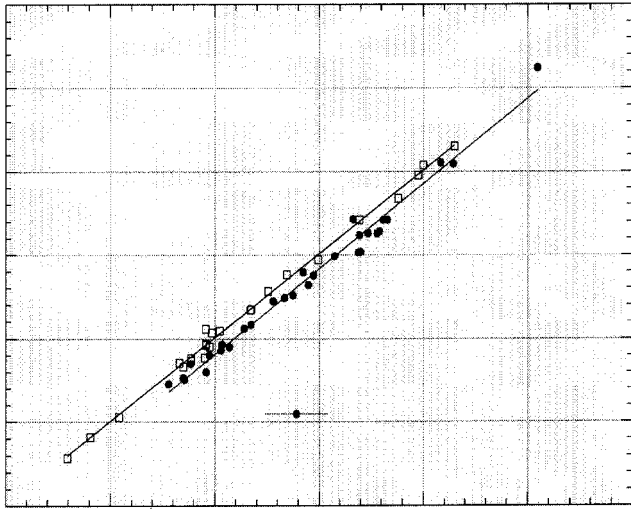


Figure 4. Comparison of PWV measured simultaneously by two radiosondes in dual soundings. Results are grouped by calibration batch type (mixed or same).

Conclusions and Recommendations

The September Water Vapor IOP was the first of several that are planned. We expect to continue to evaluate the performance of ARM radiosondes as part of these studies. Our results indicate the following:

- Batch-to-batch calibration differences in RH may be significant at the level of accuracy required by ARM. This finding follows from analysis of the pseudo-ground-check results (which showed batch differences), by comparison of dual-sonde readings before launch, and by comparison of the PWV calculated from dual-sonde pairs.
- Within-batch variation of both temperature and RH measurements, however, is consistent with previous results and with the manufacturer's specifications. When compared to known values at the surface, the sondes were within 2% RH and 0.3° C. This observation may require a reevaluation of whether the level of accuracy required by ARM can be met by current sensors.
- Operational problems contribute to the overall observed uncertainty. More rigorous procedures are needed to minimize operator effects on the pseudo-ground-check results. Suggestions obtained by analysis of detailed profile plots (not shown) that telemetry interference contributes to uncertainty in measurements aloft, also need to be resolved.
- We are working with the sonde manufacturer to determine whether the calibration differences we observe between some batches can be characterized and reduced or eliminated.

References

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- Lesht, B. M., and J. C. Liljegren, 1996: Comparison of precipitable water vapor measurements obtained by microwave radiometers and radiosondes at the SGP/CART site. Sixth ARM Science Team Meeting, *Atmospheric Radiation Measurement Program*, 4-7 March 1996, San Antonio, Texas.